Chapter Three: Forms, Falsework, and Reinforcement

This chapter focuses on the inspection of two activities common to the construction of a bridge substructure: the erection of forms and falsework and the installation of reinforcing steel. Forms, falsework, and reinforcement for superstructures are discussed in Chapter Six.

Among the major topics of this chapter are:

- form and falsework requirements;
- form and falsework materials and designs;
- form and falsework installation;
- identification of reinforcing steel;
- delivery, storage, and sampling of re-steel; and
- re-steel installation.

Forms

Forms for concrete are like molds; they shape and support concrete until it hardens sufficiently to stand on its own. No other factor will have as much impact on the appearance of the substructure as the quality of the formwork.

Basic Form Requirements

Forms have to meet four basic requirements:

- They must be rigid enough to confine plastic concrete at the lines, grades, and dimensions shown on the form plans without bulging or sagging under the load.
- They must be constructed to be as "mortar tight" as possible to prevent the loss of concrete ingredients through joints between form sections.
- They must be able to produce a uniform concrete surface texture, including aesthetic or rustication details when such a treatment is specified.
- They must be easy to remove with minimal damage to the concrete surface.

In addition to these general requirements, the Standard Specifications also state that excavation and pile driving operations be completed before the contractor begins to construct forms at those locations. This includes:

- completing excavations to the planned bottom-of-footing elevation;
- removing material displaced by pile driving;
- cutting off or driving piling to the correct elevation; and
- completing any special foundation treatment such as the placement of a specified backfill material or foundation seal.

Form Plans

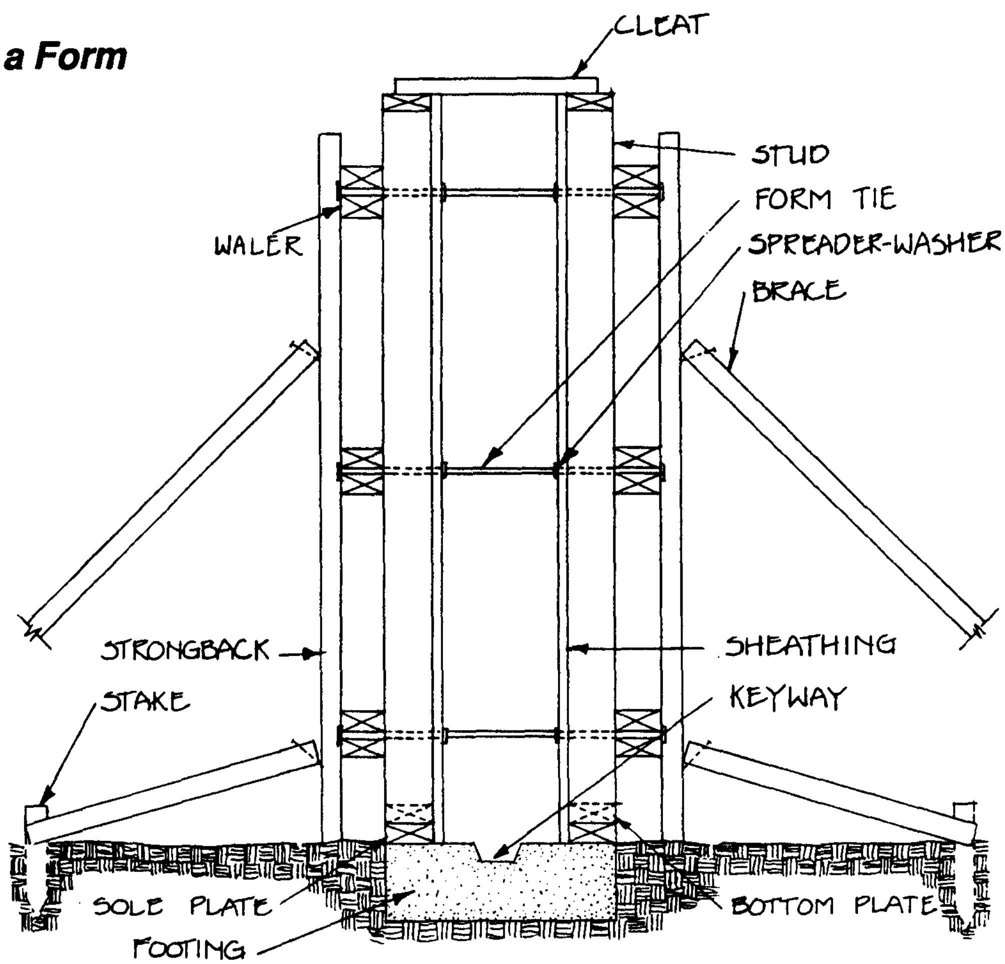
There are no plans for forms as such. The contractor uses the detail sheets of the plans to obtain the lines and dimensions of substructure units, then builds forms that will produce those dimensions and lines.

In addition to producing the correct lines and dimensions, the forms must also be capable of withstanding the pressure of plastic concrete. The faster the concrete is poured, the greater the pressure and if the concrete is poured too quickly, the walls of the form could fail. In general, the pressure is greater in taller vertical forms than it is in horizontal forms. The table on the next page, taken from the Department's General Instructions to Field Employees, gives the pressures of concrete poured into wall and column forms at various *pour rates,* the number of feet poured per hour.

Pour Rate (ft./hr.)	Pressures of Vibrated Concrete (psf) (a), (b), (c)			
	50°F (d)		70°F (d)	
	Columns	Walls	Columns	Walls
1	330	330	280	280
2	510	510	410	410
3	690	690	540	540
4	870	870	660	660
5	1050	1050	790	790
6	1230	1230	920	920
7	1410	1410	1050	1050
8	1590	1470	1180	1090
9	1770	1520	1310	1130
10	1950	1580	1440	1170

Notes: (a) Maximum pressure need not exceed 150h, where h is maximum height of pour;
(b) For non-vibrated concrete, pressures may be reduced 10%.
(c) Based on concrete with density of 150 pcf and 4-inch slump.

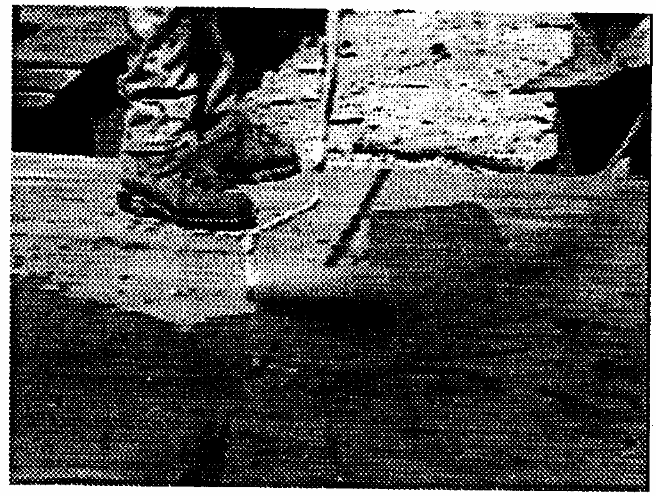
Parts of a Form



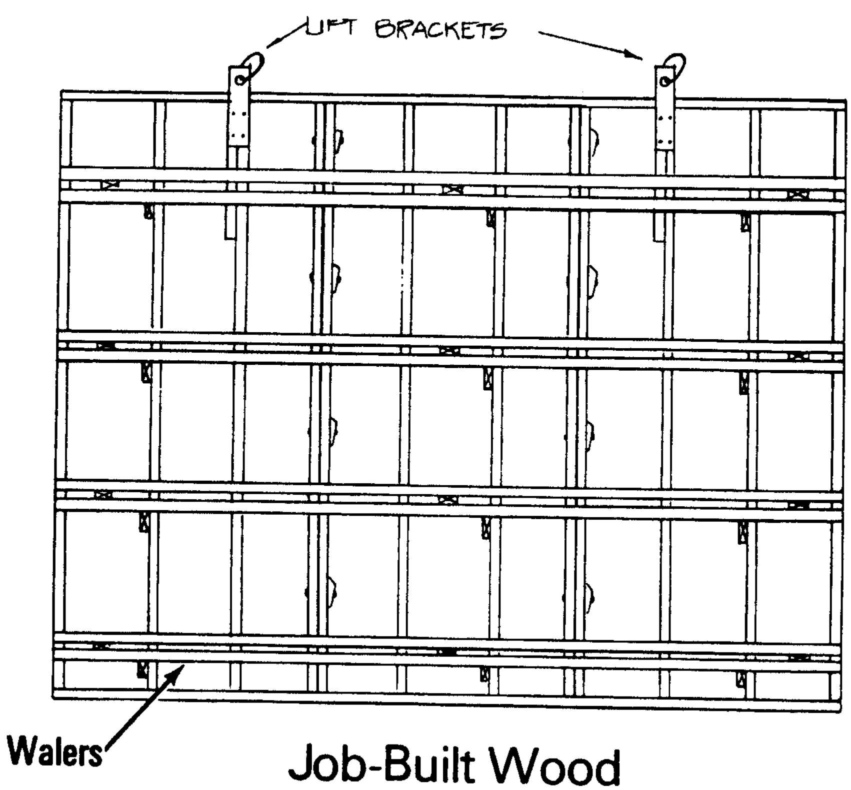
Form Materials

Forms for substructure concrete can be made from a variety of materials: wood, metal, fiberglass, and even cardboard and fiber. No matter what materials are used, however, the important thing is that they're strong enough to confine plastic concrete at the dimensions shown on the plans without bulging, sagging, or failing under the load.

Form materials should be inspected for quality and condition. All form material that will come into contact with exposed concrete surfaces except for the undersides of girders, slabs, and arch rings must be lined with approved plywood, metal, or other material that will produce the desired surface texture. The lining should be clean and free of surface defects, grease, rust, or anything else that could mar or discolor the concrete. In addition, the interior faces of form panels should be coated with a formulated *form oil* to make them easier to remove and to prevent concrete from sticking to them.



Wood and metal are by far the most common form materials. A typical wood form consists of assemblies of four-by-eight plywood sheets that have been braced vertically by *studs* and horizontally by *wales.* To provide maximum rigidity, the plywood sheets should be installed with their grain perpendicular to the studs. Studs should also be placed over all joints between sheets.

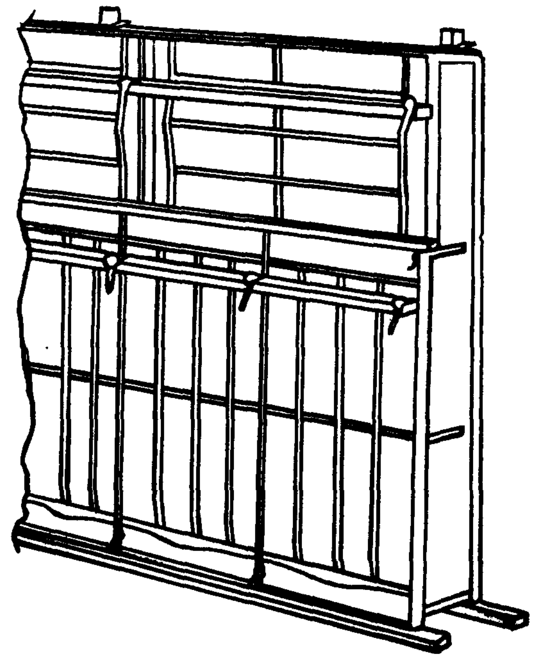


Job-Built Wood

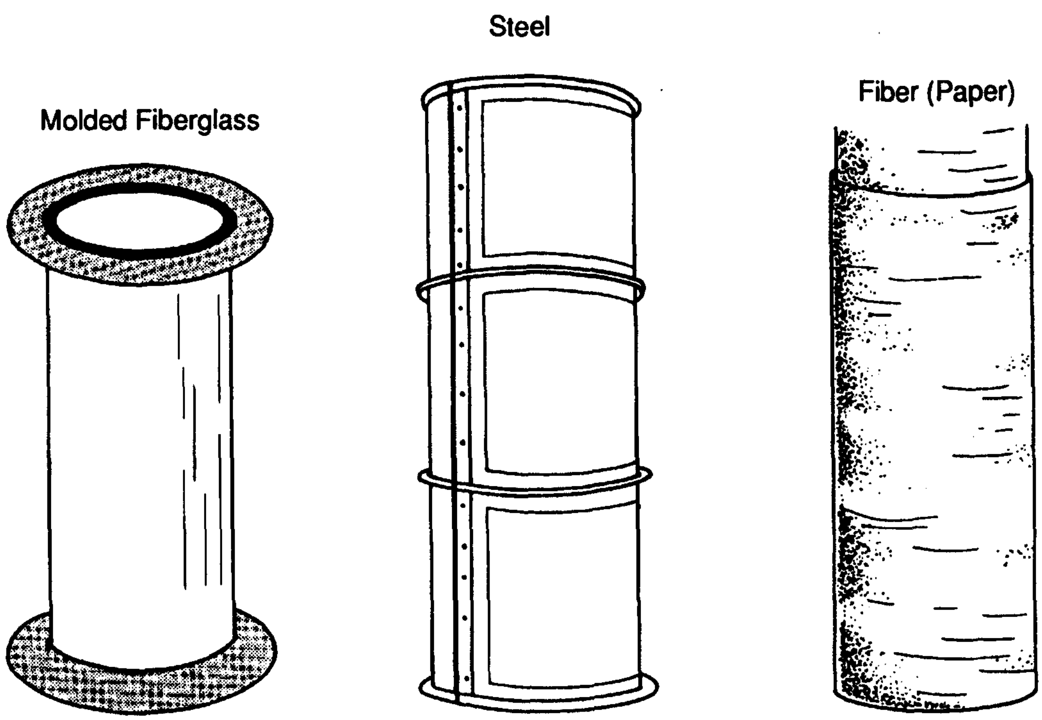
The certified tech should see that the lumber used is neither too green or too dry. Green lumber tends to shrink after installation and that can create gaps between form panels and allow mortar to leak out. On the other hand, lumber that is too old and dried out is subject to warping.

Many contractors now build and use reusable wood forms. Reusable wood forms are acceptable until they become too flexible to hold the concrete at the right lines. Surfaces of reusable forms should be checked closely for old concrete and other surface defects.

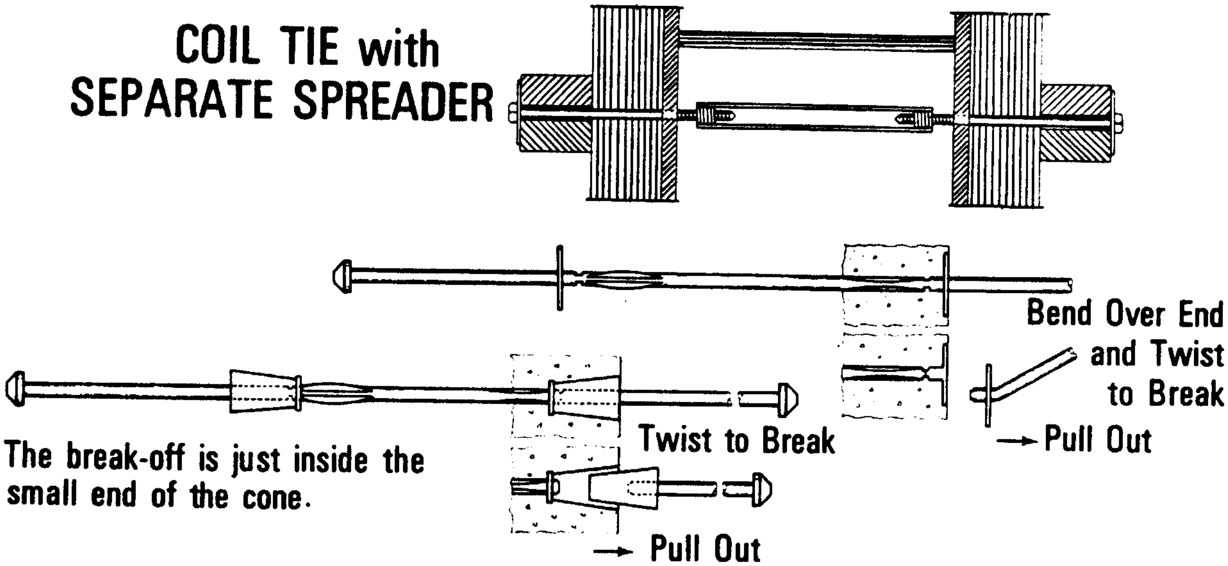
Metal forms may be used in the construction of footings and the walls of piers and abutments. They consist of ribbed metal panels that do not require additional studs and wales. When they're maintained in good condition and kept clean, metal forms can be used over and over again.



Round forms made of metal, fiberglass, or heavy fiber are used in the construction of round columns.



The sides of vertical forms are held together by form *ties.* There are a variety of designs, but most ties include three parts: a spreader rod, bolts, and washers. Many contractors use "snap" ties; the ends are designed to break off just below surface the surface of the concrete.



Form Construction

During the construction of formwork, the technician should take measurements continually to insure compliance with the approved form plans. Important measurements to take include:

- Length, width, and height. Should be compared to the dimensions shown on the plans. Final elevation and alignment must be checked by project personnel before approval.
- Spacing of the studs and wales. Studs are typically spaced 12 inches apart center to center. The spacing of wales may vary. For example, some contractors will space wales near the bottom of the form close together to provide additional bracing against the pressure of the plastic concrete which is greatest at the bottom of the form. Other contractors may use oversized wales to provide extra rigidity and space them uniformly.
- The clearance between the face of the forms and the reinforcing steel. In most cases, the minimum clearance between the form and the steel will be specified in the General Notes section of the plans; two inches is typical.

Installation of Form Ties and Spreader

The interior dimensions of vertical forms are maintained through the use of form ties and spreaders. The ties are inserted between the wales on one side, through the interior of the form, and then out through the wales on the other side. The tie bolts are tightened to draw the sides of the forms in to the planned wall thickness.

The technician should see that the tie *rods*, which will be left in the concrete, are installed so that there will be sufficient concrete cover over the rod ends; one to two inches is typical. Insufficient cover over the rod ends can cause staining and spalling of the concrete surface.

The threaded section of tie bolts should be coated with an approved lubricant to make them easier to remove after the concrete pour. Only the *threaded* section of the bolts should come into contact with concrete. If an unthreaded section of a bolt becomes embedded, it will be impossible to remove without damaging the finished surface.

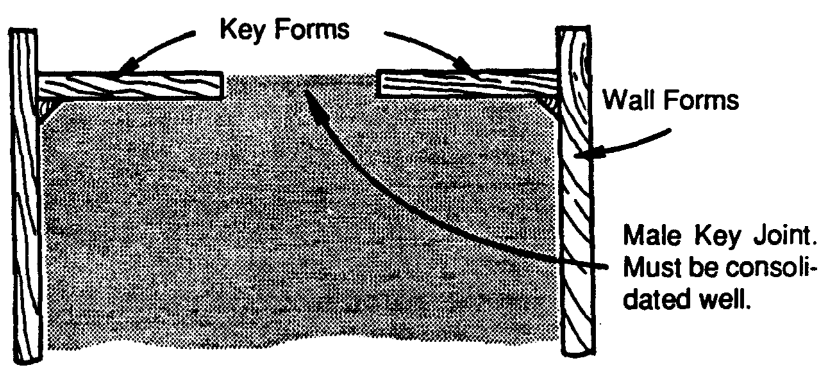
In addition to the form ties, the contractor may also use *temporary* wooden spreaders and struts to maintain the interior dimension of the form. Spreaders are used most often in tall, narrow wall forms. Wooden spreaders are not to be used, however, inside walls that will be less than two feet thick. All wooden spreaders must be removed prior to the pour.

Chamfer Strips

The contractor must install one-inch chamfer strips in all corners where the concrete would form a sharp edge and at all other locations indicated on the plans. Chamfer strips are narrow, triangular pieces of wood. They provide the concrete with beveled edges which are less likely to chip or crack. Chamfer strips are also typically installed at the top of substructure units where they not only provide a beveled edge but serve to point out the upper limit of the concrete pour, as well.

Keyways

Formwork often includes the construction of *keyways.* Keyways are simply areas of raised or depressed concrete that are formed on top of footings and at construction joints where one section of concrete will tie into the next. The locations and dimensions for keyways forms will be included on the plans.

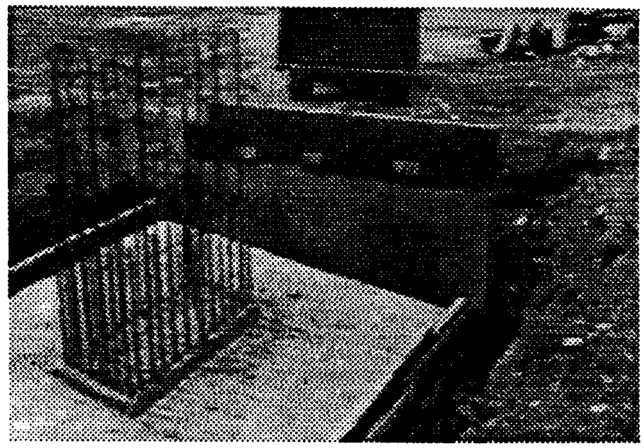


Preparation for Concrete Placement

Prior to the concrete pour, fortes should be checked with survey instruments for proper alignment and elevation. All trash and construction debris should be removed from the interior of the forms. When a form is too tall or narrow to permit easy worker access to the interior, the contractor should build in access panels near the bottom of the form to permit the removal of trash.

Removal of Forms

Forms cannot be removed until the concrete is strong enough to stand on its own without damage. On some projects, the specific time required may be determined by the results of beam or cylinder tests. On other projects, the following periods, except for days when the temperature is below 40 degrees Fahrenheit, may be used as a guide:



Centering under beams	15 days
Roadway slabs	7 days
Walls, columns, sides of beams, and all other parts	12 hours

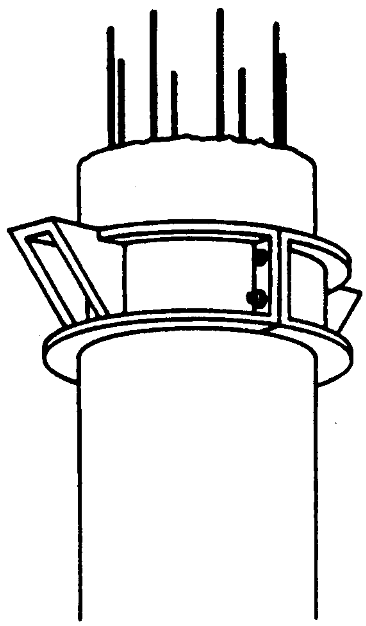
All forms should be removed carefully so as not to damage the concrete. The removal of forms is done at the contractor's risk; permission to remove them may be withheld if the Engineer feels their removal may lead to damaging the structure.

Falsework

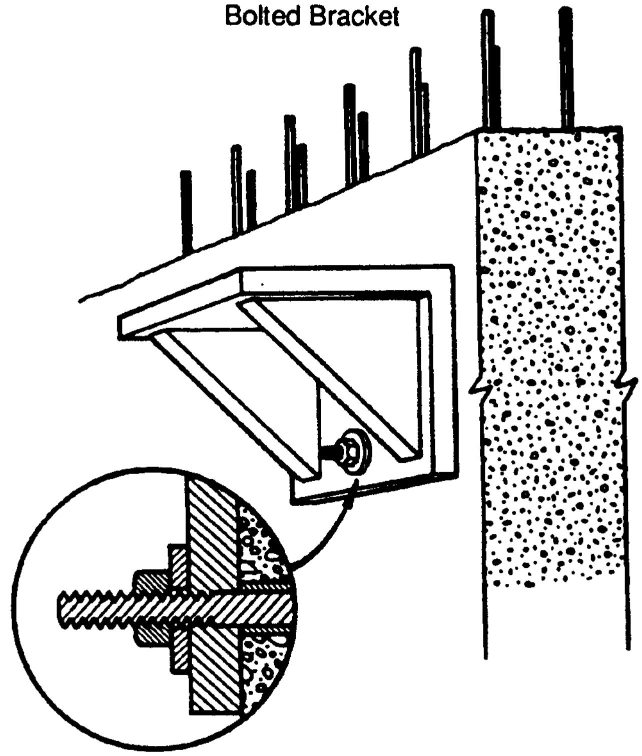
Falsework is a temporary wooden or metal framework that is built to support the weight of a structure during its construction. In bridge building, falsework is used primarily to prevent form movement during and after concrete placement. Suitable jacks and other devices are often necessary to adjust and maintain the position of falsework during a pour. Once the concrete in the structure hardens enough to be self-supporting, the falsework can be removed . . .slowly.

Falsework can range from very simple to very complex. Examples of simple types of falsework include brackets and friction collars which can be attached to columns to support forms for a pier cap.

Friction Collar

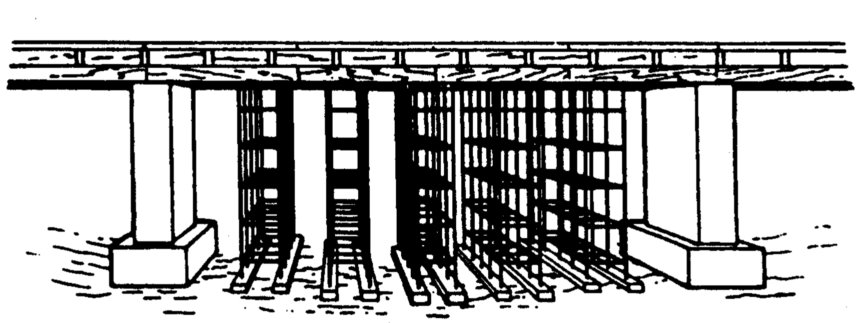


Bolted Bracket



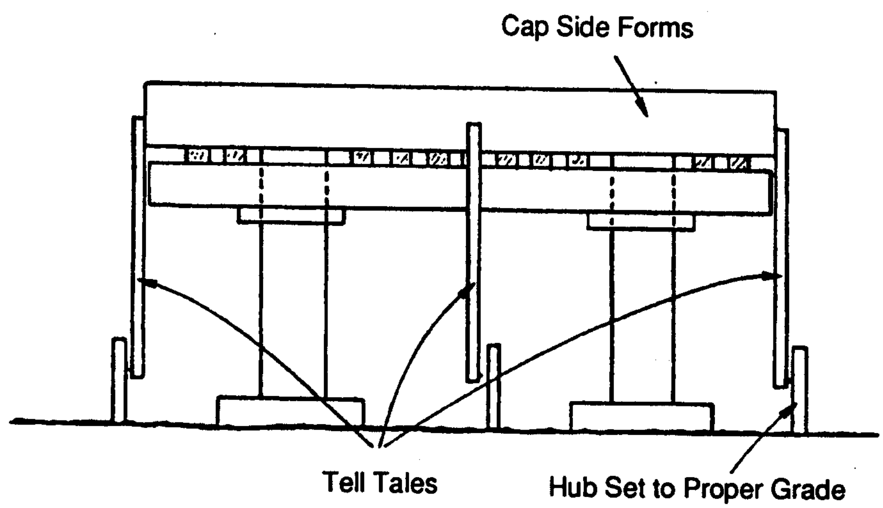
A more elaborate example of falsework is a false pier that's used to support a span between two permanent piers until the concrete slab or parapets harden sufficiently to stand on their own without serious deflection. Falsework that will bear on the foundation will require the use of mud sills , false footings, or temporary piling to provide additional support.

False Piers



The contractor must submit working drawings that show his plans for the use and construction of falsework. These drawings must be approved. Approval of the falsework plans, however, does not relieve the contractor of responsibility for constructing safe and accurate falsework.

The Certified Technician should never take for granted that the falsework is adequate; it has to be monitored throughout the concrete pour and the curing period. Simple devices called "tell tales" can be attached to falsework to measure any settlement that may occur. If movement occurs during the pour, the contractor must stop the operation and provide additional bracing. In some cases it may be necessary to put in a bulkhead or a construction joint and modify the falsework before continuing the



Section 702.14(b) of the Specifications outlines the conditions necessary to permit falsework removal, primarily time and temperature requirements regarding specific parts of a structure. Removal of falsework may also be governed by beam test results.

The removal operation should be done slowly to allow the concrete to take on its weight gradually and uniformly. Like the removal of forms, the removal of falsework is done at the contractor's risk.

Reinforcement

While formwork gives concrete its shape and texture, reinforcement gives it strength. Specifically, reinforcement provides concrete with *tensile* strength, the ability to withstand bending stresses without cracking. Earth movement, wind stresses, and the movement of the superstructure as it expands and contracts with temperature changes are examples of forces that can twist and bend substructure units. Without reinforcement, most concrete structures would crumble to the ground.

Deformed Steel Bars

The most common type of reinforcement used in bridges is deformed steel bars. "Deformed" doesn't mean twisted or bent out of shape; it refers to the raised lines or ribs on the surface of the bars. It's these ribs that enable the concrete to bond to the bars so it can take advantage of the steel's tensile strength. Smooth reinforcing steel bars would not provide as good a bond.

Bars are fabricated according to a "Bending Schedule." The fabricator produces the required number of bars at the diameters, lengths, and shapes shown on the detail sheets in the plans.

To protect reinforcing steel from rust, many projects now require the use of epoxy-coated bars in locations throughout the structure. In the past, epoxy-coated bars were reserved for areas that were more subject to moisture penetration, such as bridge decks. Researchers have discovered, however, that resteel rusting is more pervasive than previously believed. As a result, more and more projects call for the use of epoxy-coated re-steel in other areas of the structure.

Identifying Reinforcing Steel

Like many other construction materials, reinforcing steel has undergone a process of standardization. Bars are now manufactured and fabricated in the same standard sizes, weights, and grades of strength all over the country. The American Society for Testing Materials has developed an identification system which is summarized on the next page.

On the ASTM summary sheet on the next page, note that the designations for bar sizes are approximately equal to the number of 1/8 inches in the diameter of the bar: a #3 bar has a diameter of 3/8 of an inch, a #4 bar has a diameter of 4/8 or half an inch, a #6 bar has a diameter of 3/4 of an inch, a #8 bar has a diameter of one inch, and so on.

Also note the column listing the weight of each size bar in pounds per foot. This figure will be used in determining the contractor's payment for re-steel delivered and used on the job site.

There are two ASTM systems of bar identification: the continuous line system and the number system. Both systems include standard markings on the bars themselves which are used to identify the bar producer, the bar size, the type of steel used, and the bar grade. The first mark is typically the initial of the mill that produced the bar; the second mark is the bar size (#3-#18); the third mark indicates the type of steel (new billet, axle, or rail). The difference between the two systems of bar identification is in the way they identify the bar grade.

In the continuous line system, the grade of steel is indicated by one or two lines located between the main ribs of the bar. One line between the main ribs indicates the steel is Grade 60 (for 60,000 psi strength) and two lines indicate the steel is Grade 75 (for75,000psi strength). Lower grades of steel have no grade marks.

ASTM STANDARD REINFORCING BARS

BAR SIZE	WEIGHT	NOMINAL DIMENSIONS -- ROUND SECTIONS		
Designation	Pounds Per Foot	DIAMETER Inches	CROSS SECTIONAL AREA, Square Inches	PERIMETER Inches
#3	.376	.375	.11	1.178
#4	.668	.500	.20	1.571
#5	1.043	.625	.31	1.963
#6	1.502	.750	.44	2.356
#7	2.044	.875	.60	2.749
#8	2.670	1.000	.79	3.142
#9	3.400	1.128	1.00	3.544
#10	4.303	1.270	1.27	3.990
#11	5.313	1.410	1.56	4.430
#14	7.65	1.693	2.25	5.32
#18	13.60	2.257	4.00	7.09

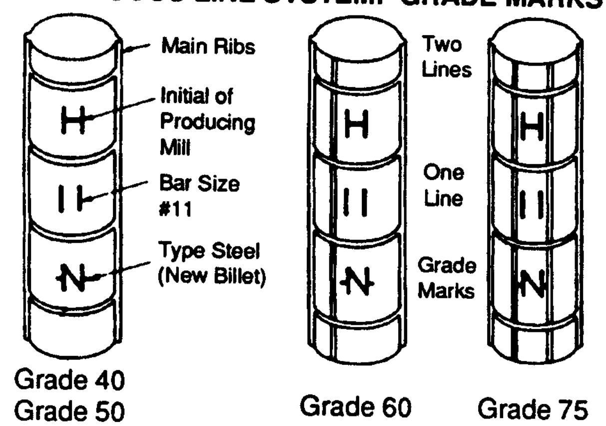
Bar numbers are based on the number of 1/8 inches included in the nominal diameter of the bar.

AMERICAN STANDARD BAR MARKS

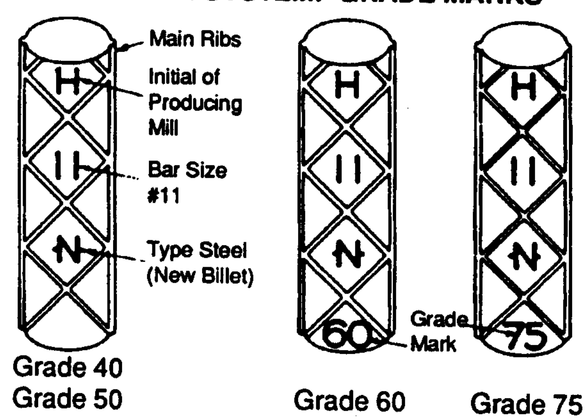
Lower-strength bars show only 3 marks (no grade mark):
1st -- Producing Mill (usually an initial)
2nd-- Bar Size Number (#3 through #18)
3rd -- Type (-N- for New Billet; A for Axle; l for rail)

High-strength bars must also show grade marks: 60 or one (1) line for 60,000 psi strength 75 or two (2) lines for 75,000 psi strength (Grade mark lines are smaller and between the two main ribs, which are on opposite sides of all American bars.

CONTINUOUS LINE SYSTEM: GRADE MARKS



NUMBER SYSTEM: GRADE MARKS



In the number system, grades are stamped on the bars numerically. Again, anything below Grade 60 will not have a grade mark.

Unless otherwise specified on the plans, all reinforcement will be deformed billet steel, grade 40 or 60; rail steel, grade 50 or 60; axle steel, grade 40 or 60.

Reinforcement Details

The technician's responsibilities for the installation of reinforcement begin with a thorough review of the detail sheets for each unit of the substructure. These details will spell out exactly what bars go where in the structure. Unless the plans say differently, all dimensions shown for spacing and clearance of reinforcing steel apply to the *centers* of the bars.

BILL OF MATERIALS FOR BENT No. 2 E.B.			
REINFORCING STEEL			
Size or Mark	Number of Bars	Length (Ft)	Weight (Lbs.)
10Ci	100	6'-0	
#10	100	29'-9	
Total #10			16,244
909	28	47'-1"	
#9	28	38'-4	
Total #9			7560
806	113	11'-4	
#8	60	36-3	
#8	71	9'-6	
Total #8			12963
603	64	16'-0	
Total #6			1538
#5	40	12'-5	
#5	108	11'-0	
Total #5			1711
404	156	9'-0	
405	84	3'-10	
Total #4			1153
301	140	12'-6	
302	140	7'-10	
303	140	4'-6	
Total #3			1,307
Total Reinforcing Steel			42,476
CONCRETE			
Class "B" Concrete in Footing			64.8 CYS
Class "B" Concrete above Footing			54.9 CYS
Class "A" Concrete			
Pour #1			18.6 CYS.
Pour #2			4.0 CYS
Pour #3			3.8 CYS.
Columns (5@10.2 = 51.0 CYS)			51.0 CYS.
Total Class "A" Concrete in Substructure			77.4 CYS.
MISCELLANEOUS			
Surface Seal (782 SF)			L.S. Item

The first place to look for reinforcement information is in the "Bill of Materials" section on the detail sheets. It will list the sizes, lengths, and quantities of all bars needed for a particular unit of the substructure. *Straight* bars are identified by their size (for example, #10); bent bars are identified by a three- or four-digit *bar mark.*

The first or first two digits of a bar mark indicate the bar size, from #3 to #18. The last two digits indicate the mark. The mark number, 01-99, is used to differentiate between bent bars of the same size and shape but of different lengths. The detail sheets also include drawings that illustrate the *shapes* of all bent bars to be used.

The letter "E" following a bar size or mark in the Bill of Materials section indicates that bar is to be epoxy-coated.

Other useful information found in the Bill of Material section includes the quantity of each bar size and mark number needed, the lengths required, the total weight of each size bar, and the total weight of all bars. Sheet 703-BRST-01 of the Standard Drawings for bridges contains additional notes on re-steel.

Delivery, Storage, and Sampling

Reinforcing steel is typically delivered to the jobsite in bundles containing bars of the same size, mark, and lengths. Each bundle is identified by a tag that lists the number of bars in the bundle and their size. The technician should check individual bundles to make sure the proper quantities and sizes have been delivered.

Care should be taken to keep bundles intact and separated from other types and sizes of bars. The bars should be stored off the ground with enough supports that longer bars don't sag and shorter bars don't fall through. All bars should be covered for protection against harmful rust, dirt, and water. As bars are removed from the bundles, the contractor should restack the remaining bars and cover them back up.

Epoxy-coated bars require careful handling and storage; nicks and cuts that go through the coating can allow moisture to penetrate and lead to rust. Any damaged area larger than 1/4" by 1/4" has to be repaired before visible rusting occurs and with no additional payment. Extensive damage to the coating can be cause for rejecting the bar. Section 703.04 defines extensive damage.

Furnishing reinforcing steel to a contract may be performed by one of two procedures. One procedure involves certified manufacturers and coaters selected from approved source lists. When a supplier furnishes reinforcing steel from certified manufacturers and coaters, the steel may be incorporated into the work immediately without job site sampling. The other procedure involves non-certified manufacturers or coaters. Under this procedure a shipment of reinforcing steel will be job site sampled in accordance with the Frequency Manual. Samples of each bar size, grade, and deformation and from each manufacturer must be collected and submitted to the Division of Materials and Tests. The Manual and for Frequency of Sampling Testing requires the samples to be at least 72 inches long and that they be taken from each 30 tons of bar delivered to the site. Each sample submitted should be accompanied by a completed Form IT 530.

Installation of Reinforcement

Inspecting the installation of reinforcement is a matter of making sure that the contractor installs the right bars in the right locations. All bars must be properly secured to maintain the spacing and clearances shown on the plans.

The contractor can install the re-steel piece by piece or he can assemble the steel into a cage or mat that can be lifted and placed inside the forms. When the steel is assembled outside the forms, the technician must make sure the bars are tied securely to prevent displacement during the installation.

As the installation proceeds, the technician should be taking measurements at random to insure the required laps, spacing, and clearances are maintained. It's a good idea to actually count the bars used and any left over to make sure that the planned amount of reinforcement is being used.

Once the re-steel is in place, it should be disturbed as little as possible. Discourage people from walking on the mats unnecessarily and have any loose, broken, or missing ties replaced.

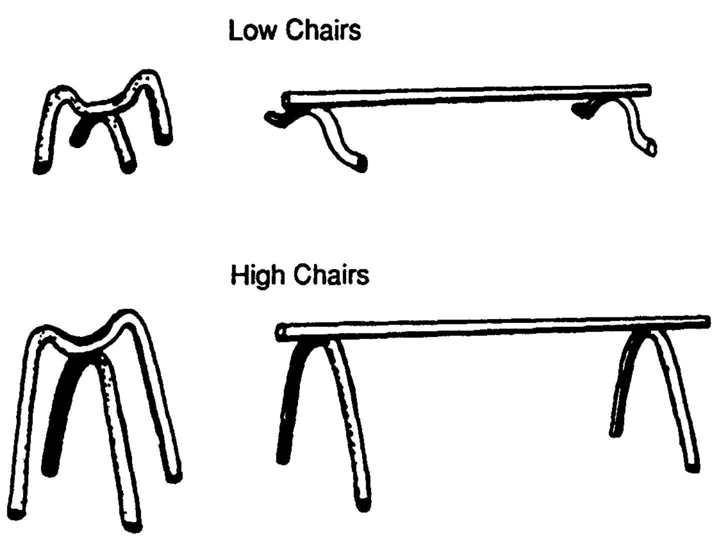
Tying Reinforcing Steel

Reinforcing steel is held in place by fastening intersecting bars with approved wire ties. Welding bars is not allowed. The Specifications require the steel to be wired rigidly at sufficient intervals to hold the steel in place during concrete operations; normally 50 percent, plus or minus, of all intersections should be tied. In all cases, the ends of the wire ties should be bent away from exterior surfaces so they won't come into contact with the finished concrete surface where they could rust and cause discoloration.

Clearances

The clearance between the re-steel and the sides of the forms determines the amount of concrete cover over the steel. Too little cover can lead to rusting of the steel. Rust, of course, weakens the steel, but it can also cause the concrete to crack and spall. That's because as rust forms it takes up space and creates pressure inside the concrete.

The plans will give the amount of concrete cover required over the steel; typical coverage is one to two and a half inches. The required clearances can be maintained through the use of approved metal supports or "chairs" that are placed between the steel and the forms. The chairs will be embedded by the concrete pour so make sure they've been approved. Approved chairs have non-corrosive tips to prevent them from rusting and staining the exterior surface.



The clearance between the bottom layer or "mat" of steel in a footing and the bottom of the footing must be maintained, as well. Appropriately sized chairs may be used there too, but some contractors will use mortar blocks instead. The blocks must be made of the same mortar mixture that will be used in the footing pour. Don't allow the contractor to use any other material -- wood, stones, broken concrete, etc. -- to support the bottom mat of steel.

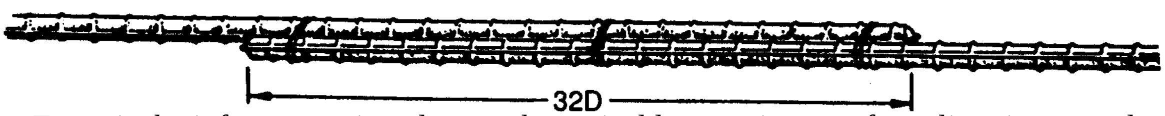
Bundling and Splicing Bars

The plans may call for bars to be tied together vertically in pairs. This is called *bundling.* In effect, bundling doubles bar strength. Bundled bars are generally found in the lower parts of tall forms where bending stresses are greatest. Bundled bars should be tied together every three feet as a minimum.

While bundling bars is done to increase strength, splicing bars is done to increase *length.* Splices are made simply by overlapping two bars then tying them together. The length of the overlap is the critical factor.

The general rule is that spliced bars must overlap one another by at least 32 times the bars' diameter. For example, Number 6 bars have a diameter of .75 inches. So, the minimum overlap for two Number 6 bars is 32 times .75 or 24 inches.

Overlapped Bars (Bar Lap)



For *spiral* reinforcement in columns, the typical lap requirement for splices is one and a half turns.

The contractor must have the PE/PS's permission to splice bars in any location other than that shown in the plans. Because splices are relatively weak connections, too many of them in the same general area can weaken the concrete. The contractor should stagger splice locations so that they're fairly well distributed throughout the structure and located at points of low tensile stress.

Splices aren't permitted at points with less than two inches of clearance between the spliced bars and the nearest adjacent bar. In general, bars that are size 14 and over cannot be lapped spliced, but may be welded or mechanically spliced in some special cases. And finally, Section 703.06 of the Standard Specifications states that construction joints cannot be used within the limits of a spliced bar.

Dowels

Lap requirements are especially critical for bars that function, more or less, as *dowels.* These vertical bars are used to connect one section of the substructure to another, forming an integral unit. They're commonly used to tie a footing into a wall or column. If the dowels don't project into the upper section by the planned amount, the connection between the sections will be weakened. The length of the bars and the distance they should project into the upper section is shown on the plans.

Bridge Seats

The spacing of the re-steel in the bridge seat area is critical. Bars that are out of position there could interfere with the placement of the anchor bolts for the bearing devices.

Method of Measurement

Reinforcing steel, except for welded wire fabric, will be measured by the pound based on the theoretical number of pounds in place as shown on the plans or placed as ordered. The quantities of materials furnished and placed shall be based upon the calculated weights of the reinforcing steel actually placed in accordance with the Specs. The weights can be calculated using the figures from this table taken from Section 703.07 of the Standard Specifications:

Size	Weight per L.F. in lbs.	Size	Weight per L.F. in lbs.
1/4"	0.167	No. 8	2.670
No. 3	0.376	No. 9	3.400
No. 4	0.668	No. 10	4.303
No. 5	1.043	No. 11	5.313
No. 6	1.502	No. 14	7.65
No. 7	2.044	No. 18	13.60

Basis for Payment

Both plain and epoxy coated re-steel are paid for by the pound at the contract unit price. Only bars that have been accepted for quality of material and installation are paid for, and no additional payment is made for wire, clips or other material used for fastening the steel in place. The cost of those items has been included in the contract unit price.

If the contractor chose to use larger bars than the ones called for on the plans -- #10s instead of #8s, for example -- payment is based on the use of the planned size.

On the other hand, if the contractor chose to use shorter bars simply to make transporting them easier and then used unplanned but approved splices to obtain the necessary lengths, the weight that is paid is still based on the lengths shown on the plans. No additional payment should be made for the extra length needed to obtain the required lap.